ART. V.—*Observations on the Movements of the Heart of the Copper-head Snake (Hoplocephalus superbus, Günth.) in and out of the Body.*

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Having already carried out a series of observations on the movements, both of progression and pulsation, in the hearts of a few specimens from each of the five great divisions of the Vertebrata, and which were communicated to the Royal Society of Edinburgh last year, I thought it might also be of interest to members of this Society, to have the results in the same direction from a few more well-known native animals.

The two specimens of copper-head snake, which supply the material for the first portion of this paper, were captured at Oakleigh, on 21st April. The larger of the two was killed on the spot, by severing the spinal cord at its junction with the brain, and the other was taken home alive to be chloroformed. Since it is part of this investigation to see the effect of different modes of death, on the after-movements of the heart, I will describe separately and briefly these two cases. The heart is situated between $\frac{1}{6}$ and $\frac{1}{7}$ of the length of the body from the head end, and consists of two auricles and a ventricle, the single cavity of which is imperfectly divided by a septum. The first snake killed on the spot in the manner indicated was $30\frac{1}{2}$ inches long when fully extended, and as Professor McCoy in his "Prodromus" gives the average as 5 ft or 6 ft. for this species, this one would be regarded as rather a small specimen. It was a male, like the other, and killed at 2.30 p.m. About $5\frac{1}{2}$ hours afterwards, it was opened up from the ventral surface, and the heart was found beating steadily at an average rate of $9\frac{1}{3}$ beats per minute, or 93 beats in 10 minutes. The heart was still within the pericardium, which was next removed, and the beats again observed. An average of 8 beats per minute

was now recorded, or 81 in 10 minutes, ranging from as low as 5 beats per minute, when there were relatively long pauses, up to 11 in a minute. The movement was less regular without, than with the pericardium, and this is in keeping with what we know of the steadying action of the pericardium and its contained fluid.

The heart was next excised about 6 hours after death (exactly at 8.39 p.m., or 34 minutes after the body was opened up). The auricles alone contracted for the first minute, then the ventricle began, but at a much slower rate than the auricles. Hence the ventricle and auricles did not contract in unison, but independently. The ventricle contracted at first at an average rate of 4½ times per minute, or 22 times in 5 minutes, while the auricles in the succeeding 5 minutes contracted 92 times, or on an average of 18½ times per minute. During the same period, the ventricle only contracted 18 times, or about one-fifth as often. The ventricle gradually began to beat at distant intervals, sometimes even of ten minutes, and finally ended with three beats at intervals of 1, 1, and ½ minutes respectively. The ventricular contraction entirely ceased 23½ minutes after excision. Meanwhile, the two auricles continued to beat as near as may be together, but the left auricle ceased about the same time as the ventricle. The right auricle still continued beating steadily at a rate of 8 beats per minute, then it gradually became enfeebled, and ceased to beat about 35 minutes after the left auricle.

Thus the ventricle and left auricle beat for about 6½ hours after somatic death, and the right auricle for about 7 hours, and almost exactly one hour after excision of the heart. For purposes of comparison, however, we will reckon the excised heart as a whole, and the pulsations would then cease with the ventricle, or 23½ minutes after excision. Both ventricle and auricles reacted to stimulation, such as the prick of a pin after spontaneous beating had ceased. The ventricle was found to do so for over 45 minutes, and the right auricle for about 15 minutes. The temperature of the room was pretty constant throughout at 19° C., and the heart was simply laid out on a moistened plate.

The second and much smaller snake, measuring only 16 inches, was killed with chloroform. The effect of the chloroform was, that the snake coiled itself up and remained perfectly motionless, all but the tip of the tail. This moved to and fro for about 10 minutes, then quivered only,

and finally the snake was removed from the vessel with its mouth now gaping. The heart was first observed with the pericardium intact, and had an average of 39 beats per minute for the first 3 minutes. The pericardium was next slit up, and the heart exposed, and the average for 3 minutes was 23 beats per minute. The heart was now excised, 14 minutes after the removal of the snake from the chloroform. At first it beat very slowly, only about 8 per minute, then it increased after 20 minutes to an average of 31 beats per minute, and at the end of an hour it was beating at the average rate of 33 per minute. Throughout this period the beating was regular, that of the ventricle and two auricles alternating in regular succession.

When observed two hours after excision, the rate of beat of ventricle and auricles was very disproportionate. While the auricles beat in unison at an average rate of 27 per minute, the ventricle only averaged 9 beats per minute, or one-third that of auricles. Three hours after excision, the auricles averaged 22 beats per minute, and the ventricles only 6, or for 3 minutes in succession, 5, 6, and 7 beats respectively. Shortly afterwards the ventricle ceased to beat, a little over 3 hours after excision. In this instance there was no response to stimulation, at least 30 minutes after cessation of spontaneous beating.

The times of the principal events may now be given. Chloroform was administered at 11.27 a.m., snake taken out at 11.42 a.m., heart excised at 11.56 a.m., ventricle was seen beating feebly but fairly regular at 3 o'clock, p.m. ; observed 20 minutes afterwards, and there was no sign of beating, even after watching for some time, so that the excised heart in this instance beat for at least 3 hours 4 minutes. Both auricles continued beating in unison, and 4 hours after excision the average number of beats per minute was 28, the left, however, feeble as compared with the right auricle. Five hours after excision, the average in both was 24 per minute; and 6 hours after excision, the average was 18 per minute, that of the left being now exceedingly feeble. Business here called me away, so that the final beating was not observed, but probably the left auricle ceased first, as in the preceding case. The temperature here varied from 18° to 23° C., slowly and steadily increasing from the former to the latter towards the end of the observation.

A third copper-head snake was obtained on the 14th May at Oakleigh. It was a very young one, only measuring

$9\frac{3}{4}$ inches in length, and was killed with chloroform. Unlike the last, the mouth did not gape after death, but the sensitive tip of the tail trembled occasionally until the chloroform had taken fatal effect. This specimen was only removed from the influence of the chloroform after 34 minutes, and 4 minutes afterwards the heart was exposed. For about a minute no sign of movement was observed, then the beating commenced, and for 4 successive minutes the beats were 37, 46, 47, and 46 respectively. The pericardium was next removed as delicately as possible, and the beats fell to less than half the above, although only two minutes elapsed between the two records. The beating, however, was very regular, and for 3 successive minutes gave 21 per minute. The heart was now excised, and the beating at first was rather irregular. Two minutes after the last record the beats were 20 per minute, and for 10 minutes in succession, 36, 40, 15, 17, 25, 28, 30, 31, 32, and 33 respectively, or an average of about 29 beats per minute.

During the first three minutes after excision, a very interesting phenomenon presented itself. The heart travelled along the moistened plate in the direction of its base, and thus progression as well as pulsation exhibited itself. As I was always prepared for such a movement, the plate on which the heart was laid out had marks to indicate the slightest progress. The distance travelled happened to be the length of the heart itself, viz. $\frac{5}{12}$ inch, and the rate of progression $\frac{3}{12}$ inch the first minute, $\frac{1}{12}$ inch each the second and third minutes.

There is something positively grotesque at first sight in an excised portion of the body, such as the heart, beating away and moving along at the same time, but I had become so familiar with this progressive movement in the excised heart of the frog, that it was to me not an unexpected occurrence.

In the excised beating heart, there is an exhibition of energy which is merely a continuation of the habitual work of the organ, but in the excised moving heart, there is a display of power for which we are unprepared. Just as in the detached gill, labial palp, or foot of the mussel, we might expect ciliary motion to continue, but not necessarily the progressive movement which they exhibit. The cause of this progressive movement in the latter case is evident, being due to the cilia; but how the excised heart is propelled, and why in the direction of base or apex, I leave to others

to determine. This much may be stated generally, that it will be the strong muscular contractions of the ventricular walls which will produce the movement. The fibres there are arranged spirally (at least in higher Mammals), and as each spiral contraction drives the blood forward when the heart is attached, so the force normally employed in doing so is now expended in sending forward towards the base the detached heart itself. The short and sharp contraction of the ventricle might be supposed to give a jerking action to the progressive movement of the heart, and as a matter of fact, in the frog's heart it was so; but here, the heart seemed to glide gently along, as if an intermittent source of energy was converted into a continuous movement.

There is likewise a deep interest attaching to such movement, not only as showing the abounding vitality possessed by the heart, even when out of the body, but as exhibiting in a very appreciable form the force and direction of the heart's energy. In the rabbit and kitten it is the same direction, but in the frog it is mostly the opposite, or apex-ward, and thus there is an important difference in the behaviour of the excised Amphibian heart, as against the Reptilian and Mammalian hearts. There is no occasion to enter into a detailed explanation of this fact now, but it may be noted in passing, that Drs. Waller and Reid* state in connection with their electrical examination of the isolated heart, "all our observations support the theory, that the contraction proceeds from base to apex" in the frog, and "that the contraction begins at the apex and ends at the base of the ventricles" in the Mammals.

Resuming the record of the beats, this was as a rule taken every half-hour. The first half-hour after excision, three successive minutes gave 34, 35, 35 respectively, the beats being very regular and with vigorous stroke. The second half-hour the beating was still regular, but weaker, and 28 beats per minute for three minutes in succession were recorded. Fifteen minutes afterwards, 21 and 20 beats per minute were recorded. The third half-hour the beating was still fairly regular, and ran for five minutes in succession 20, 23, 22, 23, 23 respectively. The fourth half-hour the beating was steady, but feeble, and gave for 5 minutes in succession 17, 15, 16, 16, 16 respectively. The fifth half-hour showed very feeble beating, and a perceptible

* Phil. Trans., 1887, B. and Nature, Vol. xxxviii, 1888.

exhaustion of energy. In four successive minutes, 10, 12, 14, and 13 beats were recorded. Shortly after, the heart practically ceased to beat, although up to this the entire heart beat—ventricle and auricles—in regular alternation. Ten minutes after the last record there was no visible movement of the ventricle, although five minutes later the left portion of it showed very faint movement, but soon ceased. There were still very faint indications of movement at the junction of the auricles and ventricle, but we may say that the heart ceased to beat as a whole nearly three hours after the administration of chloroform, and two and a half hours after excision. The exact times were :—Chloroform administered 8.15 ; taken out 8.49 ; heart excised 9.5 ; last recorded beat of ventricle (13) at 11.38 and certainly still beating feebly at 11.40 ; so that the excised heart beat as a whole for 2 hours 35 minutes at least.

The contrast in the time of pulsation between this and the previous heart, is marked, both of which were taken from chloroformed snakes. The former with its auricles beating for 6 hours at least, and its ventricle for fully 3 hours, while the latter only pulsated altogether for about $2\frac{1}{2}$ hours after excision. An explanation, however, lies in the fact, that a large portion of the heart's store of energy was used up in the progressive movement, for it was usually found in the frog's heart that the duration of pulsation was lessened when progressive movement occurred. The temperature was pretty constant throughout at 20° C.

Summing up the principal results obtained, they may be presented as in the following table, which gives only the maximum results in each case :—

TABLE I.

Heart.	Mode of Death.	In Pericardium.	Without Pericardium.	Excised.	Duration of Pulsation of Excised Heart.	Temp.
No.		Per min.	Per min.	Per min.	Hours. Minutes.	C.
1	Severing spinal cord	$9\frac{1}{3}$ beats	8 beats	$4\frac{1}{2}$ beats	— $23\frac{1}{2}$	19°
2	Chloroformed	39 ,,	23 ,,	33 ,,	3 4 (at least)	18°–23°
3	Do.	47 ,,	21 ,,	40 ,,	2 35 (at least)	20°

As regards the beats per minute, they vary considerably according to circumstances. The pulse-rate of the snake,

according to Colin,* is 24 beats per minute, or according to Burdach,† 34 per minute, but from the above table, it is seen that this rate is exceeded when the heart of the chloroformed snake is observed, either attached and within its pericardium, or detached.

It may be mentioned that in the chloroformed snakes, the right auricle was distended with blood, while the left was flabby and empty. The explanation usually given, that the heart is distended after death by chloroform, owing to its want of power to contract, is negatived by these observations; for surely it will be conceded, that a heart which can execute movements and pulsate for hours, is not lacking in a considerable amount of stored up energy. But a probable explanation of the fact that the right side of the heart retains its blood, while the left side is deprived of it, lies in this, that the lungs (in this case lung) cease to perform their proper functions, that respiration is arrested, and so blood ceases to be received by the lungs through the pulmonary artery, or from them through the pulmonary veins, although the muscular, still living and active heart, continues to pulsate. And this suggests the question—Can a body be said to be dead entirely, while the heart within it is living and active? Death is the cessation of vital activity, but we cannot say that the progressing and pulsating heart does not exhibit activity of a vital kind, so that somatic death need not include cardiac death. Poets, novelists, and even scientists have spoken of the pulse of the heart being stilled by the gentle hand of death, but there may be death to all outward appearance, and still the heart beats—life at least cannot be said to be extinct. Professor MacAlister, of Cambridge, says‡ that stoppage of the heart and cessation of life are simultaneous in man and the higher warm-blooded animals, but I have observed the excised heart of a kitten to travel $\frac{1}{2}$ inch forward and $1\frac{1}{2}$ inch to right, and pulsate as a whole for 5 hours 12 minutes. It seems to me that death can only be accurately defined as stoppage of the heart's action, or rather, if this action be regarded as due to nerve substance, then the death of the nerves, or that part which co-ordinates, would be the final test. At present, however, in the Vertebrata at least, we may speak of partial or somatic death, and complete or cardiac death.

* See Landois and Stirling's Text-book of Physiology.
† Physiologie, Vol. iv, p. 25.
‡ Man, Physiologically Considered. Religious Tract Society.

I may briefly refer in conclusion to the results already obtained from the comparative study of the excised hearts of fish, frogs, reptiles, birds and mammals. As regards the movements of the heart, they are usually stated to be those of pulsation alone, but we have now to add progression and what I have ventured to call rhythmic quivering. This consists of a feeble quivering movement, after the regular visible beating has ceased, and which may last for a considerable time.

The following Table (II) gives the movements of pulsation and progression of excised hearts in the five classes of verebrate animals, with the maximum result obtained in each case :—

TABLE II.

——	1. FISH (Australian Smooth Hound)	2. FROG (Green and Golden Bell Frog)	3. TORTOISE (Long-necked River Tortoise)	4. COPPER-HEAD SNAKE (Young)	5. BIRD (Common Fowl)	6. RABBIT (Young)	7. KITTEN
	Min. Sec.	Hours.	Hrs. Min.	Hrs. Min.	Min Sec.	Mm. Sec.	Hrs. Min.
Duration of pulsation	10 20	5 to 6 (at least)	6 23	3 4	1 15	24 50	5 12
Distance traversed	—	$1\frac{1}{8}$ in. in 2 min.	—	$\frac{5}{12}$ in. in 3 min.	—	$\frac{5}{16}$ in. in first few minutes (exact time not recorded)	$\frac{1}{2}$ in. forward, $1\frac{1}{2}$ in. to right, mainly in 2 min.
Direction of progression	—	Apex, & towards left usually	—	Base—straight forward	—	Base, with slight inclination to left	Base, and to right, ultimately nearly transverse

In frog, snake, and kitten, chloroform was used as the means of death, so that these results are strictly comparable. Such investigations have evidently important bearings on all questions relating to the heart, and the nature of its action even within the living body. Incidentally, too, they throw important light on the effects of chloroform upon the heart's action. They show that when the breath is out of the body, the heart may be still beating away and capable of considerable exertion.

The now celebrated Hyderabad Chloroform Commission proved conclusively that, under chloroform, respiration ceased before the heart; for in the entire 571 animals experimented on, including dogs and monkeys particularly, and a few horses, goats, cats, and rabbits, this was invariably the case. Chloroform was, as a rule, administered very freely, and the maximum time the heart continued to beat after respiration ceased was 11 minutes in the dog, and 12 in the monkey. No doubt in the human subject, chloroform is not administered to the healthy, and the highly sensitive heart cannot long survive the death of the body; but making due allowances, the comparative study of excised hearts, justify and support the conclusions of that Committee, that death is not due to failure of the heart's action. And the record of cases of resuscitation, when surgeons have pronounced the patient dead, such as the one mentioned by a Surgeon-major of the Bengal Medical Service in the *Lancet* where he says, "I succeeded after about twenty minutes of the hardest work I ever had," enable us to indulge the hope that deaths from chloroform administered for medical purposes, will become rarer and rarer, especially with the young. The practical conclusion of the whole matter is, that while there is pulsation of the heart, there is hope.